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TECHNICAL REPORT

The forensic holodeck: an immersive display for forensic crime scene reconstructions

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Abstract
Purpose In forensic investigations, crime scene reconstructions are created based on a variety of three-dimensional image modalities. Although the data gathered are three-dimensional, their presentation on computer screens and paper is two-dimensional, which incurs a loss of information. By applying immersive virtual reality (VR) techniques, we propose a system that allows a crime scene to be viewed as if the investigator were present at the scene.
Methods We used a low-cost VR headset originally developed for computer gaming in our system. The headset offers a large viewing volume and tracks the user's head orientation in real-time, and an optical tracker is used for positional information. In addition, we created a crime scene reconstruction to demonstrate the system.
Discussion In this article, we present a low-cost system that allows immersive, three-dimensional and interactive visualization of forensic incident scene reconstructions.

Keywords Forensic medicine · Virtopsy · Crime scene reconstruction · Immersive virtual reality

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Introduction

In the last century, photography has been established as the tool of choice for documentation of forensic information, i.e., crime scenes and accident locations. Photography is cheap, reliable, and almost instantaneous, especially since the advent of digital image capture. Photography captures a two-dimensional (2D) image of a specific object or scene; however, this view poses a problem. In recording a three-dimensional (3D) scene, the photograph stores the scene as a 2D projection only. This loss of information can be critical in a forensic environment because the quality of evidence has a direct impact on a lawsuit. Because of this problem, 3D image documentation techniques such as laser scanning and patterned light scanning were adopted by forensics from aerospace and automotive applications over the last decade [1, 2]. This process includes the documentation of crime scenes and possible injury-inflicting instruments as well as surface scanning of victims and radiological documentation of inner findings in forensic pathology using such modalities as computed tomography (CT) and magnetic resonance imaging (MRI) [2, 3]. The combination of these datasets allows for the digital reconstruction of crime/accident scenes, which results in a detailed 3D display of the incident scene with the possibility of visualization of the forensically relevant details, i.e., visualizing impact directions, bullet trajectories or attack angles [4–6]. In addition, this type of reconstruction allows for a more abstract, less traumatic presentation of the findings compared to photographs of video recordings.

The main purpose of such reconstructions is to serve as a component of an expert report for courtroom testimony. However, although the image data consist of 3D polygon models, the final visualization is presented as a 2D computer rendering because reconstructions are usually displayed as 2D projection renderings on computer screens or on paper. This display suffers from a lack of 3D perception of the scanned surroundings and could potentially create bias because the displayed perspective is preselected.

A potential solution to this problem can be found in the application of virtual reality (VR) techniques, which can simulate one's physical presence in 3D scenes via stereoscopic screens or stereoscopic head-mounted displays. The latter allow for an intuitive choice of viewpoint using gyroscopes and accelerometers to track the changes of the head position. Systems that apply the so-called immersive virtual reality techniques are in use in different fields of medical research, i.e., orthopedic and vascular surgery, psychology and behavioral sciences [7–9]. These systems consist of different sensors used to measure the orientation and position of the head as well as a head-mounted display. Based on the measured data, images are calculated separately for each eye and displayed accordingly. Traditionally, such systems are rather costly because low latencies and a good field of view are required to achieve the desired immersive effect.

In this article, we describe the prototype of a low-cost immersive virtual reality system that allows the user to walk through an incident reconstruction to gain a perception similar to that of being present at the actual scene.

Materials and methods

Hardware

The VR headset used in this work is known as the Oculus Rift (Oculus VR, Inc., Irvine, USA) and is the developer version for a device originally built to increase the immersive effects in computer games [10]. The headset consists of a screen that is split in half, thus delivering half the resolution for each eye. In the front of the screen, two plastic lenses aid in achieving a diagonal viewing angle of 110°. The device has a resolution of 1,280, 800 pixels, resulting in a resolution of 640, 800 pixels per eye. The VR glasses are connected to the PC using a high definition multimedia interface (HDMI) for image transfer and a universal serial bus (USB) to pass the information of the head orientation to the computer. Head orientation is measured using a combination of gyros, accelerometers, and magnetometers at a frequency of up to 250 Hz, allowing for a low latency between head motion and video output and thus reducing motion sickness.

To measure the position of the user's head, we incorporated an optical tracker (OptiTrack V100:R2, NaturalPoint, Inc., Corvallis, USA) into the system. The tracker measures the position of a retro-reflective marker (SORT

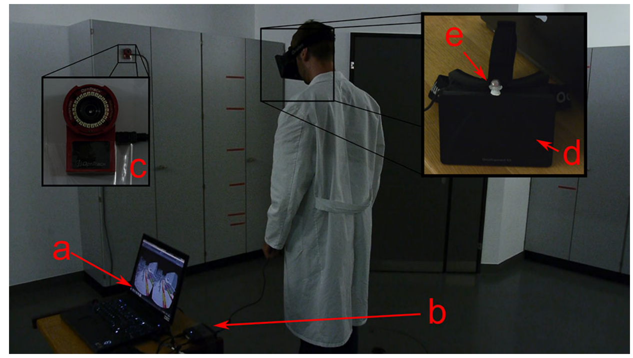

Fig. 1 System setup. **a** Computer system, **b** Oculus control box connected to the computer via USB (rotational information) and HDMI (video) connections, **c** wall-mounted tracker, **d** Oculus rift head mount, **e** optical marker for positional information

Markers, Atesos medical AG, Aarau, Switzerland) positioned on top of the VR headset. The tracker has an update rate of 100 frames per second (fps) and is connected to the computer using a USB interface (Fig. 1).

The demonstrated scene reconstructions are based on data gathered with a long-range laser scanner (Leica HDS 6000, Leica Geosystems, Aarau, Switzerland).

Software

The laser scanner generates point clouds that must be converted into polygon models for visualization, and we used Geomagic (3D Systems, Inc., Valencia, USA) for this task. Generic characters were created in Poser (Smith Micro Software, Aliso Viejo, USA), and the final reconstructions were carried out using Autodesk 3DS Max (Autodesk Media and Entertainment, Montreal, Canada).

For real-time display of the scenes, we chose a cross-platform game engine known as Unity 3D, version 4 (Unity Technologies, San Francisco, USA). For integration support for the VR-glasses, we used the Unity 4 Integration provided by Oculus VR. To support the optical tracker, we wrote a dynamic link library (DLL) in C++ using Visual Studio 2010 (Microsoft Corp., Redmond, USA) as well as Unity scripts in C#.

Demonstration scene

To demonstrate the abilities of the system, we chose the reconstruction of a shooting (Fig. 2). During an incident in an internet cafe, a known drug dealer was approached by several policemen and women in civilian clothes as well as in uniform for the purpose of arresting him. Despite being surrounded, the man was able to get up from his chair and draw a handgun. One of the policemen managed to grab onto the arm bearing the gun while the others attempted to

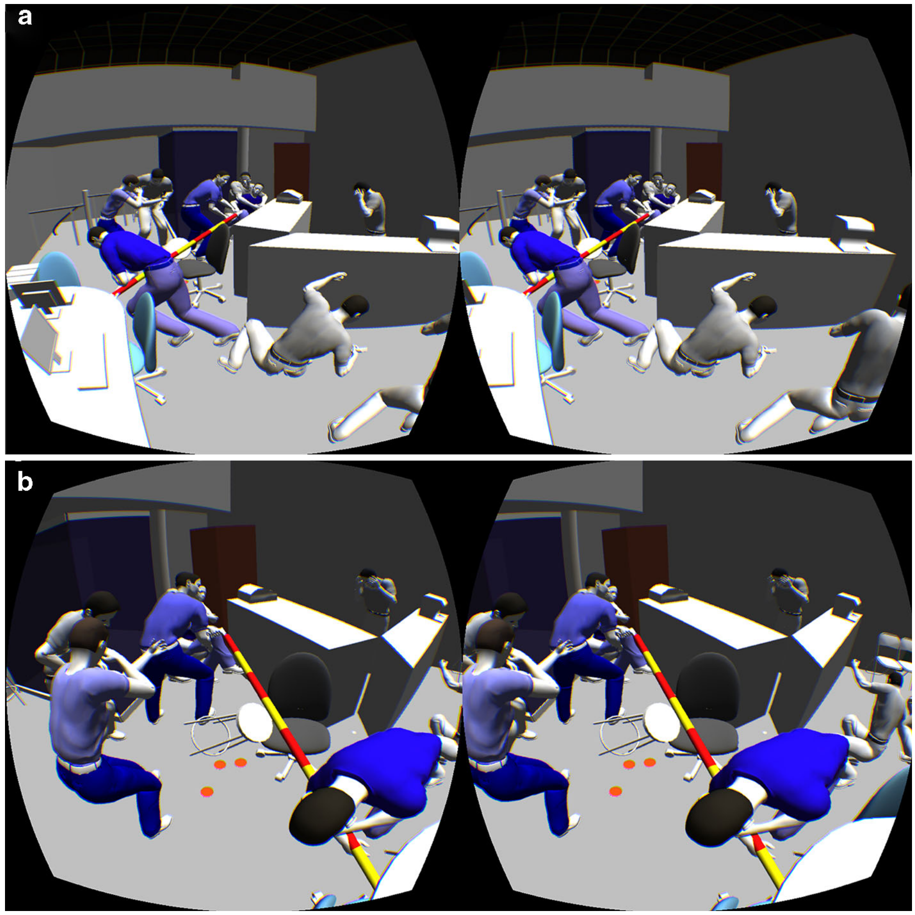

Fig. 2 Demo scene rendered in real-time with lens distortion and for both eyes. The lens distortion is corrected by lenses that are integrated into the Oculus headset to allow for a larger view volume and a better immersive effect. **a**, **b** Reconstruction based on surveillance camera footage and laser scans of the scene from two different angles. The presented gunshot (*red/yellow line*) injures one of the policemen on his hand. Reconstructions were carried out for each bullet fired (seven in total). The screenshots were taken during use of the system. From **a** to **b**, the user repositions themselves to get a better view on the presented bullet trajectory

take cover. In the course of the struggle, seven gunshots were fired. One of the bullets injured a policeman on his hand, and the others missed the persons standing in the room. The entire scene was recorded by a surveillance camera located in one of the top corners of the room, and the recordings were used to reconstruct the sequence of events. Based on a laser scan of the surroundings, the final position of the projectiles, and the camera footage, the scene was reconstructed with one reconstruction for every gunshot fired. The aim of the reconstruction was to assess how close the bullet trajectories came to severely injuring one of the persons in the room.

Discussion

In this article, we present a system for immersive display of forensic reconstructions using low-cost VR gaming technology. We present a sample case that shows how such a system could be used.

In Switzerland, incident scenes are routinely reconstructed by combining a variety of modalities ranging from 3D laser scans of the scene to post-mortem surface scans and medical image modalities, i.e., CT and MRI. The purpose of these reconstructions is to create a visualization of an event to make it possible for a state attorney or judge to properly assess a situation based on the bullet trajectories, visibility, speed, distance, etc. Although the data on which these reconstructions are based are of high resolution and allow for a spatially correct display of the scene, current visualization methods usually require a projection of the 3D reconstruction onto a 2D display, which means a reduction of spatial information. Although 3D screens are readily available at a low cost, estimating distances is still difficult because the perceived depth depends on the size of the display.

A solution to this problem could be the use of VR glasses that offer a proper 3D view of the scene. We chose a new generation of VR glasses that are designed as a low-cost product for gaming and are therefore available off the shelf. The device can be head mounted and measures the orientation of the head in real time, allowing for calculation of the scene with the correct perspective. With a view angle of 110°, the device offers a good immersive effect. Because the intended use of the device is gaming, positional information of the head is usually not required. To overcome this problem, we use an optical tracker to measure the user position, thus allowing the user to freely move inside the virtual scene. This method of adjusting the view is much more intuitive than the use of a gamepad or mouse and results in less motion sickness. During a police congress, we were able to demonstrate the system, and the comments by the police officers involved in the presented incident were promising.

However, there are certain issues that must be resolved. Presentations using this system should always be guided by an expert who can direct the user. The version of the VR glasses we used has a low resolution, resulting in a slightly blurry vision with visible pixels. According to the manufacturer, the final version of the glasses will have a higher resolution to avoid these issues. The volume in which the user can move is currently limited by the length of cables and the limited view volume of the tracking camera. Use of several tracking cameras would increase the view volume as well as the tracking accuracy of the camera axis. Because the system is designed to be used in lawsuits, it must exhibit realistic depth perception, which is not guaranteed by the VR glasses developed for computer gaming. Further tests must be carried out to determine the optimal parameters that will produce the best possible depth perception. In addition, the reconstructed scenes must be optimized for the system. The polygon count should be sufficiently low to allow for real-time rendering and therefore to decrease motion sickness. Also, the absence of textures can influence 3D perception, an issue that also should be considered. Finally, it is not fully understood yet, how such a system could practically be used in a lawsuit—options are virtual, expert-guided tours, predefined positions from which the user can inspect the scene or fully free movement within the scene as presented in this article. Also the amount of systems required might limit its use, especially for legal systems with a jury based court.

Future work should include an expansion of the movement area by either use of longer cables or a wireless connection in combination with several trackers. In addition, the possibility of an expert interacting with the system i.e., by marking points of interest, placing arrows or changing the position of the user in real-time might give the expert additional explanatory tools.

Tests on the realism of the images in terms of depth perception and viewing angle are also required, followed by guidelines on how to create suitable scenes. Issues such as the low resolution should be resolved with the technical progress of such systems in the course of the following years.

To summarize, we present a low-cost system that allows for immersive, three-dimensional, and interactive visualization of forensic incident scene reconstructions.

Key points

1. Incident scene reconstructions are often based on 3-dimensional modalities such as CT, laser scans, and 3D surface scans.
2. Standard display methods reduce 3-dimensional reconstructions to 2-dimensional projections, which incurs a loss of information.
3. The presented system is low cost and allows an interactive, intuitive 3-dimensional display of incident scene reconstructions.

References

1. Bolliger MJ, Buck U, Thali MJ, Bolliger SA. Reconstruction and 3D visualisation based on objective real 3D based documentation. Forensic Sci Med Pathol. 2012;8:208–17.
2. Thali MJ, Braun M, Buck U, Aghayev E, Jackowski C, Vock P, et al. VIRTOPSY—scientific documentation, reconstruction and animation in forensic: individual and real 3D data based geometric approach including optical body/object surface and radiological CT/MRI scanning. J Forensic Sci. 2005;50:428–42.
3. Dirnhofer R, Jackowski C, Vock P, Potter K, Thali MJ. VIRTOPSY: minimally invasive, imaging-guided virtual autopsy. Radiogr Rev Publ Radiol Soc N Am. 2006;26:1305–33.
4. Buck U, Albertini N, Naether S, Thali MJ. 3D documentation of footwear impressions and tyre tracks in snow with high resolution optical surface scanning. Forensic Sci Int. 2007;171:157–64.
5. Buck U, Naether S, Braun M, Bolliger S, Friederich H, Jackowski C, et al. Application of 3D documentation and geometric reconstruction methods in traffic accident analysis: with high resolution surface scanning, radiological MSCT/MRI scanning and real data based animation. Forensic Sci Int. 2007;170:20–8.
6. Buck U, Naether S, Räss B, Jackowski C, Thali MJ. Accident or homicide-virtual crime scene reconstruction using 3D methods. Forensic Sci Int. 2013;225:75–84.
7. Lin Q, Xu Z, Li B, Baucom R, Poulose B, Landman BA, et al. Immersive virtual reality for visualization of abdominal CT. In: Proceedings of the SPIE, 2013, p. 8673.
8. Völter S, Krämer KL, Niethard FU, Ewerbeck V. Virtual reality in orthopedics: principles, possibilities and perspectives. Z Für Orthop Ihre Grenzgeb. 1995;133:492–500.
9. Brault S, Bideau B, Kulpa R, Craig CM. Detecting deception in movement: the case of the side-step in rugby. PLoS One. 2012;7:e37494.
10. Oculus VR|Oculus Rift. Virtual reality headset for immersive 3D gaming. Irvine, CA: Oculus VR. http://www.oculusvr.com. Accessed 8 Jan 2014.